FNAL Proposal
May 3, 1978

Spokesman: Lawrence W. Jones
University of Michigan
Ann Arbor, MI 48109
(313) 764-4443

A Sensitive Search for Massive

Neutral Long-Lived Particles

H.R. Gustafson, L.W. Jones, M.J. Longo,
T.J. Roberts and M.R. Whalley

Department of Physics
University of Michigan
Ann Arbor, MI 48109

Proposal Summary

We propose to make a very sensitive search for long-lived neutral particles of m ≥ 3 GeV. The proposed search should have a sensitivity more than adequate to detect neutral particles pair-produced with a cross section comparable to the Upsilon. R. Cahn has suggested that the lowest-mass particles with naked beauty may be stable. The experiment in the M4 beam would use time-of-flight and calorimetry to measure v and E and hence m.

Purpose of the Experiment

In an earlier experiment, E 330[1], our group made a search for massive, neutral, stable hadrons in the M4 beam in the meson lab using time-of-flight (relative to the accelerator rf) and calorimeter pulse height to determine energy and velocity for neutral hadrons. No explicit objective, for mass or cross section, was available in that search beyond the general notions of integrally-charged quarks (as proposed by Pati, Salam, Han, Nambu, etc). Now Cahn[2] has proposed that the meson states $\mathcal{B}^{\pm}$ and $\mathcal{B}^{\circ}$ composed of quarks $b\bar{u}$, $\bar{b}u$, $b\bar{d}$, and $\bar{b}d$ should have a mass of about 5 GeV and might be absolutely stable against strong, electromagnetic, and weak decays. As he noted, E330 was less sensitive than required for such particle production, assuming pair production with a cross section comparable to the Υ, by about two orders of magnitude. Subsequently there have been three proposals (E-469, the E-288 group, and P- 578 by our group) to search for such particles in charged beams. If the mass splitting between $\mathcal{B}^{\pm}$ and $\mathcal{B}^{\circ}$ is small, as expected, the β decay lifetime for decay of one to the other is longer than the proper time of any of the beam particles in this or the other proposed searches ($\sim 2 \times 10^{-7}$ sec). If a $\mathcal{B}^{\pm}$ is found, the existance of the $\mathcal{B}^{\circ}$ is begged. If the $\mathcal{B}^{\pm}$ is not found, the $\mathcal{B}^{\circ}$ should still be sought; the mass splitting could be much greater than anticipated.

Experimental Technique

The method proposed is identical to that used in E330 with modifications to improve the sensitivity significantly. The E4 calorimeter would be used in the M4 (meson lab K°) beam line with a timing signal derived from the accelerator rf. With a flight path of 600 m the time delay Δt of a particle relative to $\beta = 1$ particles is $\Delta t = 1/\gamma^2$ microseconds. Thus for $\gamma = 10$ (E = 50 GeV for m = 5 GeV) the time delay is 10 ns, about midway between rf buckets (19 ns). The range spanned from 4 to 16 ns corresponds to γ from 8 to 16. For energies above 40 GeV E 330 had virtually no events with $3 < \Delta t < 16$ ns; we observed a time resolution of 0.88 ns for energetic neutrons. Even this might be improved by running the accelerator to maintain tight rf bunching on the flat top.

The rates in this experiment could be improved over E 330 by opening the aperture of the collimator to 8 x 8 inches (20 x 20 cm^2) from the 1 mm^2 aperture used before. This aperture was used before because of the neutron (and K°) rate which lead to problems of pile up, etc. with more than $\sim 10^4$ n/pulse. We did make a short run (1 day) with the 4 ft Fe beam stop in place, and with the collimators opened to about 5 x 5 cm^2. From these data we obtained our best limit on hadrons with an interaction cross section in iron smaller than neutrons.

We propose here to limit the neutron flux with a 3.7 m Be absorber, providing an attenuation for neutrons of 10^4.

The Λ^0 should interact with an inelastic $\sigma \sim 10$ mb (on protons) corresponding to about 75 mb on a Be nucleus, hence with $\lambda \simeq 108$ cm. The attenuation of a 3.7 m Be absorber for the Λ^0's would then be 30. With 3×10^{12} protons per pulse interacting in the target we should have $\sim 10^3$ neutrons per pulse through this absorber into a 1.1×10^{-7} sr aperture (20×20 cm^2 at 600 m) together with a somewhat greater, lower-energy K^0 flux.

During the previous experiment some few events were seen at times between pulses and with energies falling as $\sim 1/E$, although no mass band was observed.[1] There are 3 ways that we hope to improve the rejection of spurious events; (1) we will locate the calormieter in a tunnel portion of the M4 enclosure so that it is shielded from cosmic ray air showers; (2) we will baffle the calorimeter with a more elaborate array of anticoincidence counters, and (3) we will operate a muon telescope in conjunction with the beam line to veto occassional beam spill spikes. It was our experience before that our "event" signals were rate dependent, and that a spill monitor is most important. We have also learned with our current beam dump exercise (same calorimeter) in M2 the importance of redundant veto counters.

Beam Line

We would use the M4 beam with a 3.7 m Be absorber as far upstream as possible and variable collimators at ~ 400 ft. Otherwise, sweeping magnets and vacuum pipe the remainder of

the beam line are all that is required. The calorimeter should
be as far toward the end of M4 as possible while still below
earth cover.

Rates

If the $\mathcal{D}^o$ and $\overline{\mathcal{D}^o}$ pairs have m $\simeq$ 5 GeV, lifetime $\geq 10^{-7}$ sec,
$\sigma(\mathcal{D}N) \simeq$ 10 mb, and are produced with a cross section comparable
to the T, we may estimate rates as follows. From Lederman
et al[3] the T is produced with

$$B \left.\frac{d\sigma}{dy}\right|_{y=0} \simeq 3 \times 10^{-37} \text{ cm}^2$$

for P+N $\rightarrow$ T $\rightarrow$ $\mu\mu$. If B $\simeq$ 0.05,

$$\left.\frac{d\sigma}{dy}\right|_{y=0} \simeq 6 \times 10^{-36} \text{ cm}^2.$$

The $p_\perp$ distribution for the T and presumably for the $\mathcal{D}^o$ is
broad; let us assume $\frac{d\sigma}{dp_\perp^2} \propto e^{-1p_\perp^2}$, so that $\langle p_\perp \rangle \simeq$ 1 GeV/c
(acutally 0.886 GeV/c). Then

$$\frac{E}{p_L^2} \frac{d^2\sigma}{dp_L d\Omega} \simeq 2 \times 10^{-36} \text{ cm}^2.$$

Take $\langle p_L \rangle$ = 60 GeV, δp_L = (80-40) = 40 GeV, and $\delta\Omega$ = 1.1 $\times 10^{-7}$.
We further assume $\mathcal{D}^o$'s are made with $\sigma \propto A^1$, so that the rate
of production of $\mathcal{D}^o$ is

$$N(\mathcal{D}^o) = N(p) \frac{\delta\sigma(\mathcal{D}^o)}{33 \times 10^{-27}} \times 2 \times 0.7$$

where 2 $\simeq$ $A^{1/3}$, N(p) is the number of interacting protons,
and a factor 0.7 is included because the beam at 60 GeV

corresponds to $p_\perp \sim 0.4\text{-}0.5$ GeV so that $d\sigma/dp_\perp^2 \cong .7(d\sigma/dp_\perp^2)_{p_\perp=0}$. With these factors,

$$N(\mathcal{D}^\circ) = 2.2 \times 10^{-14} N(p).$$

With 3×10^{12} protons interacting in the meson target per pulse, $N(\mathcal{D}^\circ) \cong 6.7 \times 10^{-2}$ per pulse or one per ~ 15 pulses. With a factor of 30 attenuation this assumed production cross section would result in one detected $\mathcal{D}^\circ$ in 450 pulses or about one every 1 1/2 hours.

Requested Running Time

We would require ~ 2 weeks for setup, debugging, and tuning and ~ 4 weeks (400 hours) for data collection. A total request then of 6 weeks or 600 hours would suffice for a sensitive search.

Integration with other Experiments

This experiment would be integrated with others involving our Michigan group (Gustafson, Jones, Longo, Roberts, and Whalley), in particular P-583 (J. Rutherfoord; pBe $\rightarrow \mu\mu$) and P-579 (L.W. Jones, neutron polarization). We would wish to schedule this experiment during a period when the neutral hyperon beam was using the M2 beam line, and when M3 was unavailable for P-579. Like P-579 this is a modest proposal in terms of lab requirements, beam time, etc. We could be ready to run immediately after the mesopause.

Requirements

We would provide the detector and computer. Our needs from Fermilab are only the PREP electronics and the beam as described above.

References

1. H.R. Gustafson, C.A. Ayre, L.W. Jones, M.J. Longo, and P.V. Ramana Murthy, Phys. Rev. Lett. $\underline{37}$, 474 (1976).

2. R.N. Cahn, Phys. Rev. Lett. $\underline{40}$, 80 (1978).

3. L.M. Lederman, Invited paper HA4, Bull. Am. Phys. Soc. $\underline{23}$, 590 (1978).